APPENDIX 2 JAMES RIVER CHLOROPHYLL STUDY

DRAFT STUDY PLAN FOR REVIEW AND UPDATE OF
JAMES RIVER SITE-SPECIFIC NUMERIC CHLOROPHYLL-*A*
WATER QUALITY CRITERIA

SUMMARY

DEQ intends to undertake a comprehensive review of the existing James River Site-Specific Numeric Chlorophyll-*a* Criteria for the tidal James River and associated modeling framework. The following draft study plan illustrates how this review and update may be conducted.

Task #1. Identify stressors, stressor indicators, and the technical approach. Recent research indicates high potential to improve chlorophyll-*a* criteria based on linkages with harmful algal blooms (HABs). The first task is to establish the specific approach and focus areas for technical evaluation. Time-frame: 6 months

Task #2: Define relationships between HAB indicators designated use attainment. Perform literature reviews, data analysis, and laboratory testing to determine densities of HABs that impact designated uses such as fish and shellfish, and recreation, and the causes of the impacts. Time-frame: 2.5 years.

Task #3: Develop relationships between HAB cell density and water quality indicators. Complement existing high frequency monitoring with additional phytoplankton identification, cell density evaluations, and toxin monitoring. Use the data to derive water quality thresholds indicative of HAB cell density of concern. Time-frame: 2.5 years (concurrent with Task #2).

Task #4: Develop and apply dynamic model for indicators, nutrient inputs, and HABs. Improve the modeling of nutrient inputs, water quality indicators, and related HABs in the James River. Utilize contemporary high density chlorophyll-*a* data for model development and calibration. Refine the modeling of menhaden and oysters as top-down controls on algae. Explore the capability to either model HAB events or otherwise quantify HAB potential as a function of environmental conditions and management-related variables. Time-frame: 3 years (concurrent with tasks above).

Task #5: Adopt Criteria Update and Related WQMP Regulation/TMDL WIP Revisions. Using the results of Task #1- #4, determine and adopt appropriate revisions to the Site-Specific Numeric Chlorophyll-*a* Criteria and associated point and nonpoint source allocations for nutrients. Time frame: 2 years, partly concurrent with Tasks #4.
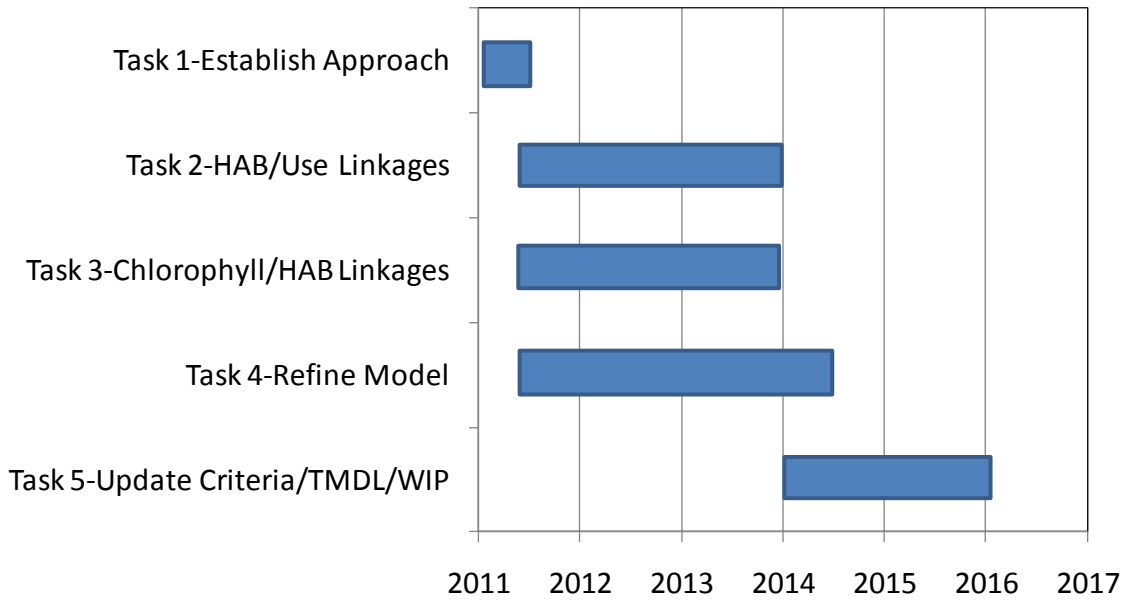
Figure 1—Recommended schedule for chlorophyll-*a* criteria reevaluation process.

Study Period

By many tasks running concurrently (Figure 1), the time period needed for a thorough review and update process is limited to an estimated five years, well within the seven year Stage 1 implementation period associated with the Chesapeake Bay TMDL. The time period for the lower salinity segments might be shorter due to more predictable water quality and algal dynamics.

DETAILED TASK DESCRIPTION

The six tasks identified above are described in greater detail below:

Task #1. Identify stressors, stressor indicators, and technical approach

The first task in the standards revision process would to attain a scientific consensus on the preferred technical basis of refined standards. Although this could take several forms, it is recommended that strong consideration be given to linkages with harmful algal blooms (HABs). Marshall and others (2005) compiled a listing of 30 potentially toxic phytoplankton species in the Chesapeake Bay and its tributaries in Virginia. Several of these taxa are known to occur in either the upper or lower James River estuary.

Of higher-salinity species, blooms of *Cochlodinium polykrikoides* appear to be increasing and have become an annual occurrence in the lower James River during the summer months. Dauer and others (2008) found increasing trends in dinoflagellates in the lower James River, noting blooms of *Cochlodinium polykrikoides* in 2007 accompanying the trend.

Recent laboratory studies have shown this species is toxic to multiple fish species and shellfish in North America (Gobler et al., 2008; Mulholland et al., 2009, Tang and Gobler, 2009). Proportional relationships between *C. polykrikoides* cell density, chlorophyll-*a*, and toxicity provides a potential basis to establish the standard to designated uses. However, additional technical discussion is needed to gain consensus on this overall approach. Additional HAB species beyond *C. polykrikoides* may need to be considered in the standards development. For example, *Heterocapsa triquetra* appears to be the dominant bloom former during the spring on the lower James River but the effects literature on this species appear more limited than for *C. polykrikoides*.

In the lower salinity segments, it would be recommended to consider potential stressors such as the cyanobacteria *Microcystis aeruginosa*, some strains of which have been shown to be harmful to humans or aquatic life (Lampert, 1981; Fulton and Paerl, 1987; Fulton and Paerl, 1988). This would build upon the foundation laid by the *2007 Chlorophyll Criteria Addendum* (USEPA, 2007). Other potential stressors for discussion are the total density or proportion of cyanobacteria, with specific consideration of how these indicators could be used to predict impacts on mesozooplankton, larval fish, or other trophic levels.

It appears most of the reported HABs in the James River are located either in the low or high salinity waters. Also will consider the use and applicability of the phytoplankton IBI (Index of Biological Integrity).

Time-frame: 6 months

Task #2: Define relationships between HAB indicators and designated use attainment.

After HAB indicators are identified, it would be necessary to quantify the relations between HAB indicators (e.g., cell density or toxin concentrations) and designated use attainment. This process would consider the existing literature, supplemented with James River-specific analysis and laboratory testing as necessary.

As previously mentioned for Task #1, literature data is presently available related to *C. polykrikoides* effects on fish and shellfish. However, additional studies may be necessary to confirm and refine those relationships for the Hampton Roads area. Tang and Gobler (2009) found that the toxicity level of *C. polykrikoides* can be affected by factors such as presence of other phytoplankton in the assemblage, growth stage of the organism tested, and whether the tests are performed on culture isolates or natural bloom water. These findings along with variability in reported effects suggest there are some important issues to address if the standard is to be based on cell density. In addition, this task should seek to evaluate the biological mechanisms responsible for toxicity (e.g. toxin generation, type of toxin, physical contact, etc.). With regard to other HAB species, Landsberg (2002) provides a synthesis of effects reported in the literature. Because those results appear limited, additional testing may be needed address them should multiple species need to be considered. Task #2 could also include experimental bioassays conducted by university or contractors experienced in phytoplankton and toxicity testing.

For the lower salinity segments, the *2007 Chlorophyll Criteria Addendum* (USEPA, 2007) summarizes literature findings and some Chesapeake Bay-specific data analysis on relations between *M. aeruginosa*, microcystin concentrations, and potential harmful impacts to humans. It would be recommended to use this information as a starting point, but review and update this information to reflect the most recent literature, and ensure that the risk-based calculations are consistent with Virginia regulations/guidance.

To our knowledge, there are no microcystin concentration data for the upper James River estuary. Not all strains of *M. aeruginosa* produce toxins, and so the presence/absence of this toxin is an important data gap that should be addressed. It would be recommended to include monitoring of microcystin along with other water quality and algal monitoring in the lower salinity segments.

Phytoplankton and zooplankton are routinely monitored only at one station (TF5.5) in the tidal freshwater James River, and one station (RET5.2) in the oligohaline portion. Although these stations provide very useful data, it would also be helpful to have a better spatial/temporal characterization of potential HAB species. For this reason, it is recommended to expand plankton

monitoring to up to 3-5 stations in the lower salinity segments, contingent upon available funding.

Need to also consider the link between HAB indicators and designated uses to include two approaches: 1) food-web and fisheries and 2) public health and socioeconomics. Recent literature shows that HABs can have profound negative impacts on the local economy and public health. A literature and data analysis should be accomplished within ½ year while laboratory testing could take the full 2.5 years planned.

To ensure efficient use of resources, further development of the appropriate laboratory testing for this study is needed.

Time-frame: 2.5 years.

Task #3: Develop relationships between HAB cell density and water quality indicators

Cell density or toxin concentrations would be a more direct measure of HAB-related impairments than chlorophyll-*a* concentration. However, chlorophyll-*a* or other water quality indicators could be more amenable to monitoring and modeling, and could be used as an indicator of HAB potential in conjunction with cell density and/or toxin data. To be used in this fashion, it would be necessary to demonstrate empirical relations between *the* water quality indicators and the HABs of interest.

Recent data indicates a regression relationship exists between *C. polykrikoides* cell density and chlorophyll-*a* (unpublished data). A refinement of this relationship (and for other species if necessary) would provide a connection between chlorophyll-*a* concentration and impairment of designated uses. Available data has been largely collected from peak algal blooms. Additional data may be needed to assess the relationships during pre- and post-bloom conditions when the algal assemblage is more diverse.

For lower-salinity segments, the *2007 Chlorophyll Criteria Addendum* (USEPA, 2007) provides an analysis of relations between *M. aeruginosa* cell density and chlorophyll-*a*, largely drawing on data from northern segments. Owing to its unique characteristics, the James River estuary has different cell density-chlorophyll-*a* relations than observed in other regions (unpublished data). It is recommended to develop these empirical relations using James River-specific data.

To address Task #3 segments, the existing HRSD Dataflow program and similar efforts in the upper estuary should be complemented with extensive phytoplankton identification and cell density results. Although the Dataflow program is very effective at determining chlorophyll concentrations at a high level of temporal and spatial resolution it does not provide data on species composition needed for this aspect of the standards development. Data collected in Task #3 is needed to develop chlorophyll thresholds indicative of HAB cell density of concern.

Potential testing under Task #2 may also address any "cause and effect" between HABs and fisheries. In order to assess the relationship during pre- and post-bloom conditions, a much more

comprehensive monitoring strategy may be needed. Since blooms are highly localized temporally and spatially, a scheduled monitoring program at pre-determined stations may not capture such events. Therefore, a special monitoring plan with rapid response capabilities may be needed.

Time-frame: 2.5 years (concurrent with Task #2).

Task #4: Develop and apply dynamic model for indicators, nutrient inputs, and HABs.

This task is associated with making substantial improvements to the modeling of water quality indicators and related HABs in the lower James River. The Chesapeake Bay Program's existing water quality model was designed to simulate seasonal averages in chlorophyll-*a* and estimate the effects of nutrient reduction on chlorophyll-*a* as step trends. Such a simplistic modeling approach cannot assess the effects of nutrient reduction on short-term bloom events. There is also reason to believe that the lower James River chlorophyll-*a* and algal dynamics may have changed relative to the present 1990-2000 calibration period given the apparent proliferation of *C. polykrikoides.* Because of these issues, there is a strong need to improve our predictive capabilities with respect to HABs. High density chlorophyll-*a* data that is now available for the area (2005-2010) would greatly assist in the development and calibration of models relative of contemporary conditions.

Improvements in modeling of chlorophyll-*a* in the lower James should also address menhaden and oysters as top down controls. Recent modeling work has shown that menhaden migration into the tributaries and associated consumption of algae has the potential to affect chlorophyll-*a.* Although present menhaden and oyster stocks do not appear to dramatically reduce chlorophyll-*a* (as long term averages) incremental effects due to increasing the size of the stock are considered comparable to some levels of nutrient reduction. Additional modeling enhancements should be made such that the menhaden migration and residence time varies according to a food gradient. A number of papers indicate that menhaden consumption of algae increases in areas with higher chlorophyll-*a*. Because the model does not presently capture these foraging effects the available reductions in chlorophyll-*a* due to menhaden (especially during bloom conditions) could be under-estimated.

Recent studies have shown that (a) initiation of *C. polykrikoides* blooms in the summer correlate with intense rains following droughts, (b) formation of blooms appears favored during conditions of vertical stratification, low winds, neap tides, and (c) certain blooms are initiated in the Lafayette and Elizabeth River and are transported to the James River (Mulholland et al., 2009; Morse et al., 2009; Morse et al., 2010). These processes represent factors that are important for the predictive framework to address. The modeling task may also require additional data collection to quantify pulsed storm water loads of nutrients (i.e., daily or weekly sampling of pulses).

It is recognized that attempts to develop and calibrate a James River model to capture short-term variations in chlorophyll-*a* and HABs would be a challenging task. To address this issue a workshop involving modeling experts and contractors is recommended to develop a path forward

and more detailed study plan than is provided here. One possible outcome of this process is that HAB events cannot be modeled or predicted with same degree of confidence normally expected of regulatory models. However, even in this case, it might be possible to better quantify the potential for HABs as a function of environmental conditions and management-related variables.

The time period after 2011 presents an opportunity to statistically evaluate the effectiveness of nutrient controls installed on the James River, particularly due to point source upgrades scheduled to be on-line after this time. This task consists of utilizing available high frequency and fixed site data to assess step trends. The results of trend analysis would be used to assist in validating model enhancements described in Task #5 relative to actual nutrient loading reductions. Dauer and others (2009) noted an apparent disconnect or substantial lag between improvements observed in NPS and PS loadings relative to observed responses in the tributaries and lower segments of the James River. Additional studies may be needed to assess storage of nutrients in sediments or other factors if continued lag-times in response are observed.

Time-frame: 3 years (concurrent with other tasks).

Task #5: Adopt Criteria Update and Related WQMP Regulation/TMDL WIP Revisions

This task is associated with translating the research results of Tasks #1-Task #4 into a water quality criteria framework. It is possible that the revised standard may be based on cell density of specific HABs and/or algal toxins, rather than only chlorophyll-*a* or another water quality indicator. This approach would be consistent with that recommended by USEPA (2007). This task should also consider establishing acceptable limits on the size and duration of HAB events, and natural factors that affect chlorophyll-*a* peaks and phytoplankton succession. The revised modeling framework would be used to determine TMDL allocations and assist the revision of the James River Watershed Implementation Plan.

Time-frame: 2 years, partly concurrent to Tasks #2-4.

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